TECHNICAL EQUIPMENT REPORT NO. F-5

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BATTERIES FOR HEADLIGHTS

by

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AGRICULTURAL RESEARCH CENTER
BELTSVILLE, MARYLAND

FOREST SERVICE
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Introduction

The dry battery, supplying the need for packaged electricity to many devices, is one of the common and most necessary articles used by firefighters. Important technological developments stimulated by World War II and the "Space Age" has brought a sudden demand for new batteries. This has led to improved types for existing applications, as well as new batteries to meet new service requirements. With each new use there has been a change in design to give maximum service.

This report gives some information on the relative efficiency of new design types of "D" cells, water-activated batteries, and other types which may be adapted for Forest Service use.

Purpose

Manufacturers have shown considerable interest in making batteries which meet the general requirements of the Forest Service. They have furnished us engineering samples of batteries and invited our comments and recommendations. This cooperativeness from industry has been utilized by making laboratory evaluation tests and providing field tests to determine whether the batteries meet our needs.

Objectives

1. Comparative information on the different grades of "D" cells.[1/] Standards in industry for batteries of the same type are not too consistent. For example, batteries classified as "industrial" types by different manufacturers differ widely in life characteristics, total capacity, storage life, etc.

   One manufacturer makes five different kinds of flashlight size "D" cells, under classifications of regular, industrial, heavy-industrial, activator, radio, and energizer, each with a

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1/ Standard size flashlight batteries as described in National Bureau of Standards Circular 559, April 20, 1955 and approved as an American Standard by the American Standards Association. The nominal dimensions of this cylindrical cell are 1-1/4 inches in diameter and 2-1/4 inches in height.

different price. These batteries are intended for a particular type of service, though the claims of the manufacturers are sometimes not clear; there can be situations where one type of cell will be more satisfactory than the one designed specifically for that service. This makes it difficult to choose the best battery for the intended service.

2. Shelf Life.

Large quantities of dry cell batteries are thrown away each year due to deterioration in storage. This report covers a limited investigation of the magnesium-cuprous chloride (water-activated) battery. The main features of this battery are indefinite storage without deterioration and a constant voltage throughout its useful life. An investigation of the effect of shelf storage on the various types of "D" cells is also covered in this report.

Procedure

The test that best represents any particular service is that which most nearly duplicates the rate-of-energy output of the battery when in actual use. Although the main service of the batteries is in headlights, use of a lamp load was discarded because it would introduce a variable that would tend to make direct comparison of the batteries less valid. A resistive load of 40 ohms for a group of four cells (6 volts) represents the average load of the prevalent type of lamp in use. Use of a group of 4 cells averaged any small irregularities between cells. Individual voltage was recorded on each cell to see that there was fairly uniform behavior and no "duds". An end-point of four volts was used because minimum usable light from a headlight occurs at this voltage and most published data usually specifies one volt per 1-1/2 volt cell as a nominal end-point.

The tests that we used approximately duplicate conditions of our particular use where the goal is to furnish the best possible light output from headlights for a minimum of eight hours continuously (in night-shift firefighting, for example). Continuous discharge reveals the general discharge characteristics more quickly, but these characteristics are not conclusively related to results obtained in intermittent tests. Our intermittent duty test cycle of eight hours discharge with sixteen hours recuperation time was chosen to determine if more than one night's service could be obtained with the more expensive grades of "D" cells.

The tests were made when the batteries were fresh and after they had been stored at room temperature for given lengths of time.

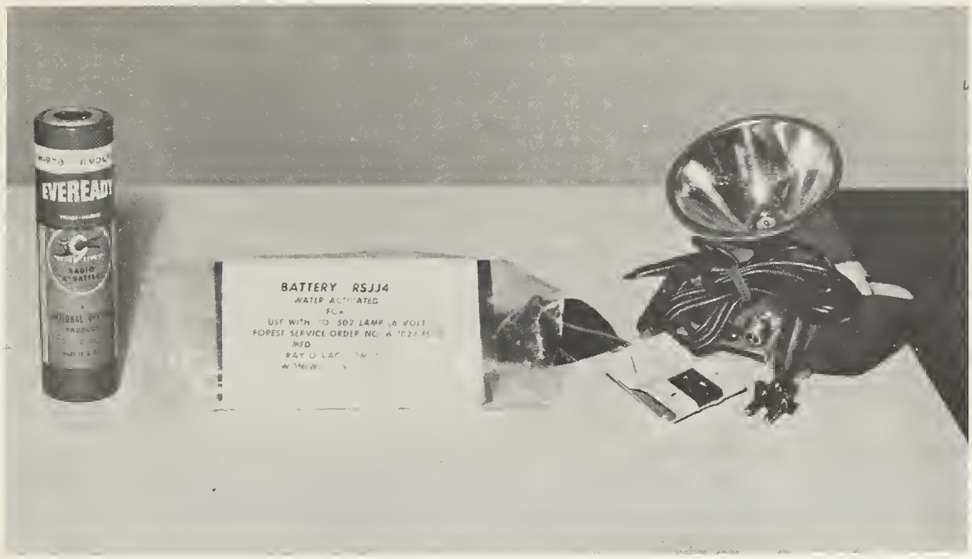

Figure 1. Dry, alkaline, plug-in battery; water-activated battery; economy headlight.

Price quotations of all "D" cells tested were obtained from the manufacturers. These prices are used to show the price variation of the different grades of cells.

All cells were inspected visually for corrosion at the time they were removed from storage. Corrosion of "D" cells is defined here as visual evidence of perforation of the zinc can or corrosion of the positive terminal.

Samples of dry and water-activated plug-in batteries, designed especially for the economy headlight[2/] were purchased and distributed to the regions for field tests with sample headlights. (fig. 1).

Description of Tests:

(a) Continuous Duty.

Each group of four cells was discharged continuously through a resistance of 40 ohms. Voltage readings were taken periodically and recorded automatically. The test was continued until the closed circuit voltage fell below 4.0 volts.

(b) Intermittent Duty.

2/ A new plug-in, lightweight, inexpensive headlight (Forest Service Specification 150).

Each group of four cells was discharged through a resistance of 40 ohms for eight hours followed by a sixteen-hour rest period. Voltage readings were taken periodically and recorded automatically. The test was continued until the closed circuit voltage was less than 4.0 volts at the beginning of an eight-hour discharge period.

Types of Batteries Tested

"D" cells made by the following manufacturers were tested:

1. The Ray-O-Vac Company.

   (a) 2LP - regular, general purpose, LeClanche.3/
   (b) 3LP - industrial, LeClanche.
   (c) 5LP - premium, LeClanche, "Sportsman".

2. The National Carbon Company (Eveready).

   (a) 950 - regular, general purpose, LeClanche.
   (b) 1050 - heavy-industrial, LeClanche.
   (c) A100 - radio, LeClanche.
   (d) D99 - industrial, LeClanche.
   (e) E95 - energizer, alkaline MnO_2 mix.

Special plug-in batteries for headlight applications:

1. The Ray-O-Vac Company.

   (a) RSJJ4 - magnesium-cuprous chloride battery, water-activated, six-volt.

2. The National Carbon Company (Eveready).

   (b) W-978 - special six-volt battery made up of four "1/2D" alkaline cells (E94) in series connection.

Figure 2.
"1/2D" cell, left
"D" cell, right

3/ This name is used in honor of the man who in 1868 discovered the zinc-manganese dioxide mix used in this cell.

Results

1. "D" Cells.

(a) Continuous Duty.

The service is described as the total number of hours, the total number of ampere-hours, and the average drain current before the potential fell below 4.0 volts (Table 1).

(b) Intermittent Duty.

The service is described as the total number of hours of actual discharge, the total number of ampere-hours, and the average drain current before the potential fell below 4.0 volts (Table 1).

(c) Classification.

"D" cells are classified according to service life in hours to an end-point of four volts as follows:

Class	Continuous (hours)	Intermittent (hours)
I	10-12	12-15
II	13-20	14-25
III	21-29	26-34
IV	Over 30	Over 35

The batteries discussed in this report are then classified:

	Class I	Class II	Class III	Class IV
	2LP	5LP	3LP	E95
	950	1050		
		A100		
		D99		
Price Range Each	(.05-.11)*	(.08-.16)	(.13)	(.32)

*Though the prices for cells in Class I are quoted in this range, this type of cell is a standard GSA stock item at .05 or .06.

(d) Discharge Characteristics.

Comparative discharge curves (continuous and intermittent) of cells of all classes are shown (figs. 3 and 4).

TABLE I
BATTERY TESTS
CONDENSED DATA SHEET

Class and Battery Type	Number of Hours to 4 Volt End-Point		Number of Ampere Hours		Average Discharge Current		Percent Loss of Life in 18 Months Storage	
	Cont.	Int.	Cont.	Int.	Cont. Amperes	Int. Amperes	Hours Percent	Amp. Hours Percent
Class I								
2LP	11.70	14.5	1.5000	1.7580	.1112	.1212	15	20
950	10.75	12.0	1.3131	1.4510	.1221	.1209	21	26
Class II								
5LP	16.50	22.0	1.7820	2.7000	.1113	.1227	23	27
1050	15.00	23.0	1.8141	2.7112	.1209	.1179	40 1/	42 1/
A100	14.00	19.0	1.7060	2.2411	.1176	.1149	16	18
D99	13.75	17.0	1.6418	2.0480	.1194	.1170	13	15
Class III								
3LP	23.5	30.5	2.6800	3.8120	.1139	.1250	28	24
Class IV								
E95	67	70	8.023	8.5400	.1197	.1220	—	—
Special Plug-in Types								
Water-Activated	14		1.8893		.1349		21 2/	
"1/2D" Alkaline	18		2.1266		.1181		21 2/	

1/ Subsequent information indicates these figures may be too high.
2/ After 8 months storage (water-activated battery stored in plastic bag).

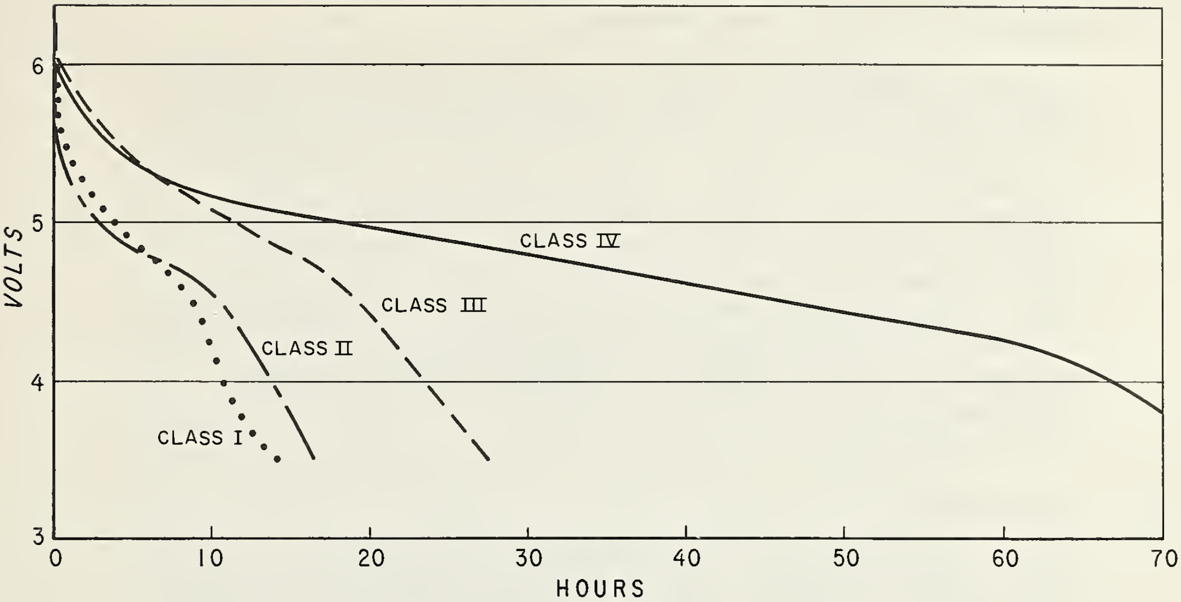

Figure 3. Continuous discharge curves for fresh "D" cells.

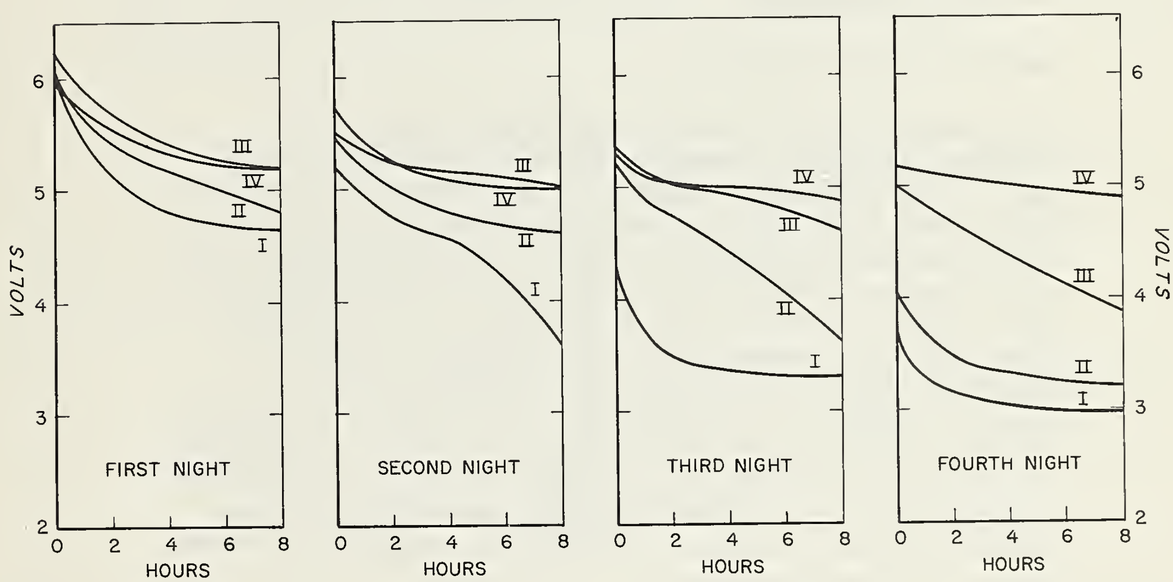

Figure 4. Intermittent discharge curves for fresh "D" cells.

(e) Leaking, Corrosion, and Swelling.

Improved cell construction has almost entirely eliminated leaking and corrosion. After eighteen months of storage at room temperature, none of the Eveready cells showed any corrosion or swelling, either before or after discharge. Five cells out of forty-eight samples of the Ray-O-Vac 3LP were corroded when removed from storage. After discharge, corrosion at the positive terminal was rapid. The manufacturer says that this is due to the use of a "hot" mix for longer life and greater capacity. If this cell is used, corrosion is more probable. Other Ray-O-Vac types showed no evidence of corrosion. No swelling was noted.

(f) Shelf Life.

After eighteen months of storage at room temperature, one brand of Class I cells showed a service life loss of about 20 percent. The average capacity (ampere-hour) and service life loss of all cells was 25 percent and 22 percent respectively (Table 1). Class I cells are below this average (23% and 18%).

2. Water-Activated Batteries.

(a) Discharge Characteristics.

The sustained higher terminal voltage of the water-activated battery is shown (fig. 5). This would produce a more brilliant light over the period of use. It takes about two hours to reach full voltage of 5.5 volts but usable output occurs in five to thirty minutes. One region made a test to determine its use intermittently. They reported a total of twelve hours of serviceable light during a twenty-three hour period. This is an indication that service life of the battery may be extended slightly by periods of open circuit. As long as moisture is present in the battery, it will continue to dissipate itself until the chemical reaction is complete, whether under load or not. Adding more water will not extend its life. Leaving the battery submerged in water reduces its service life.

(b) Corrosion.

The water-activated battery, during discharge, produces a green residue. This residue is not harmful to clothing or metals and is only mildly toxic to skin. Skin irritation can be avoided by wahing with water. Several inquiries were received about odors of the water-activated battery during storage and use. The plastic container is the offender in storage and during discharge there is a slight odor from the chemical

reaction; neither is toxic. However, the opening of large quantities of these batteries in a confined space should be avoided as the accumulated odor can be obnoxious.

(c) Shelf Life.

Though the water-activated battery is supposed to have indefinite life in storage, laboratory tests disclosed some loss in service life from batteries that were stored on the shelf and sealed in the plastic bag only. The average capacity loss for four batteries stored for eight months at room temperature was 21 percent (Table 1). The batteries required a longer period to reach operating voltage. We believe that the plastic material used as a sealed container for the water-activated battery does "breathe". Any moisture allowed to reach the battery during storage would cause partial activation. This could be a serious problem in humid climates. Therefore, water-activated batteries should be stored unopened in the original shipping cans until distributed for use. If only part of the contents of a can is used at one time, the can should be resealed to prevent any partial activation.

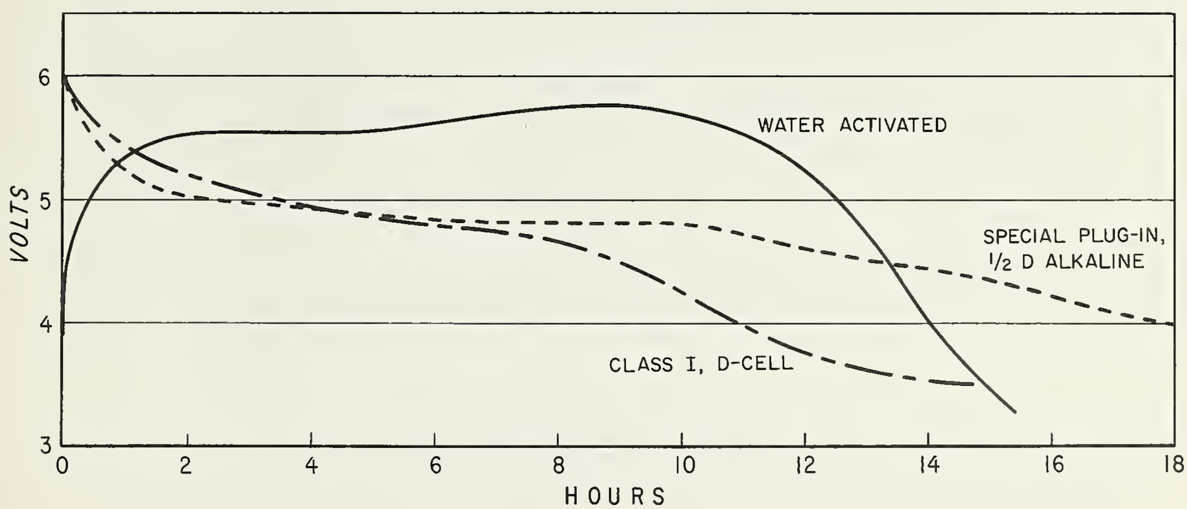

Figure 5. Continuous discharge curves for fresh water-activated and 1/2 "D" alkaline (W-978) batteries compared to Class I "D" cell.

3. Alkaline Battery (W-978).

(a) Discharge Characteristics.

This battery's service life is about 18 hours compared to 11 hours for a Class I "D" cell (fig. 5). Generally, the data presented about the Class IV cells apply to this one, except that its total capacity is reduced to the Class II category by the use of "1/2D" cells.

(b) Leaking, Corrosion, and Swelling.

The electrolyte mix used in the alkaline cells is more liquid than the zinc-manganese-dioxide LeClanche mix. The manufacturer has had the problem of providing for cell "breathing", yet effectively preventing the electrolyte from leaking. We had only two incidents of leaking and corrosion in the alkaline cells, both after complete discharge of the cells.

(c) Shelf Life.

One test made on this battery after eight months storage indicates loss of service life comparable with Class I "D" cells. More tests and field experience are needed to confirm this.

Conclusions

1. Service.

Class II cells do not give significantly longer life, on a cost per hour basis, in continuous duty tests than the cells of Class I. They do have somewhat longer life in intermittent service (8 hours on - 16 hours off) but this increase is not commensurate with their higher cost. The terminal voltage of Class II cells falls near or below four volts before the end of the second discharge period.

Class III cells are clearly superior to either Class I or II cells, both in longer hours of service and a higher average terminal voltage and on a cost per hour basis. Our experience with this type has been confined to one product (Ray-O-Vac 3LP).

The Class IV cell is in a class by itself. Its discharge curve is flatter and many times longer than LaClanche cells (Classes I, II, and III). While this cell costs about five times as much as a Class I "D" cell, it does provide proportionately longer service as related to cost, especially at heavier drains.

The alkaline (W-978) and especially the water-activated plug-in batteries will furnish larger and brighter light in headlight service than Class I "D" cells. In fact, the water-activated battery will furnish brighter light than any of the batteries tested. The present price of these new batteries (over $1 each) is not commensurate with this increased performance, but as use of them increases the price should drop making their cost versus performance position more favorable. The alkaline battery is suitable for both continuous and intermittent service while the water-activated cells can be used for continuous service only.

2. Leaking, Corrosion and Swelling.

With the possible exception of Class III cells, leaking, corrosion or swelling was not a problem in any battery tested.

3. Shelf Life.

It appears that as designs are altered in Class II and III cells to give longer service life and greater capacity, it cuts into the shelf life. It will take more data and experience to determine whether the advantages of Class II and III cells are greater than the loss in shelf life and increased initial cost.

Research and development on improving the shelf life of LaClanche cells is an active program throughout the industry. Within a relatively short time, the storage life will probably be quoted as 3-5 years with at least fifty percent of initial capacity.

Alkaline cells (Class IV and W-978 plug-in battery) have not been available long enough to make any definite conclusions about shelf life.

Water-activated batteries have indefinite storage life only if stored in their original sealed metal container. When stored only in their plastic bag container, shelf life appears to be less than that of Class I "D" cells.

Recommendations

1. Class I and Class IV "D" cells are recommended for use with the regular Forest Service headlight and other standard flashlights. The regular (Class I) "D" cell is best suited where large quantities of batteries are used and service for more than one night is not needed or necessary such as on large fires where night crews return to camp each morning. The Class IV alkaline cell is best where long service is needed to avoid carrying or supplying extra batteries to firegoers such as smokechasers or smokejumpers. Class IV cells may also be better for use by seasonal personnel and in vehicles. When using Class IV cells care should be taken that this battery does not receive automatic replacement treatment when only one-fifth of its life is expended. The tendency to consider it in the same category as an ordinary "D" cell should be avoided.

2. The alkaline (W-978) and water-activated plug-in batteries 4/ were designed for use with the economy headlight and are recommended for use with it. The alkaline battery is best suited where service will be both continuous and intermittent, while the water-activated battery is suitable for continuous service only.

   High sustained voltage and indefinite storage life are unique features that make the water-activated battery ideally suited for many Forest Service applications. Storage losses are at a minimum and more light is provided.

   The plug-in batteries and economy headlight are available from the Federal Supply Service, General Services Administration.

3. Although the batteries tested were considered primarily for use in headlights their features will in general apply to other uses as well. The use of Class IV alkaline "D" cells is recommended for use in megaphones, radios, and other electrical equipment powered in whole or in part by "D" cells where long service life is desired. Otherwise regular (Class I) "D" cells should be used.

4/ These batteries are covered by Forest Service Specifications 160 and 161, respectively.